Impacts of Cloud-Radiation-Circulation Interaction (CRCI) on Organized Convection and Extreme Precipitation

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1. Overview

Objectives: To better understand the roles of cloud-radiation-circulation interaction (CRCI) on the organization and variability of tropical convection in the ITCZ, and relationships with extreme precipitation events (EPEs) in the tropics and mid-latitude storm tracks over the North Pacific.

The Deep Tropics Squeeze (DTS) Hypothesis (Lau and Kim 2015)

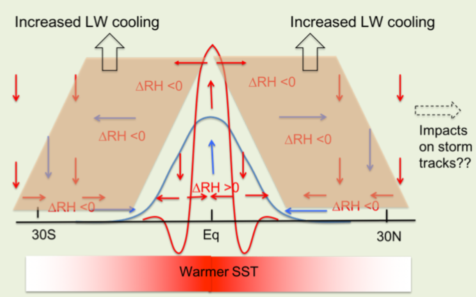

Figure 1. The "deep-tropics squeeze" (DTS) hypothesis: a deepening and narrowing of the ITCZ convective core, rise in the level of upper level divergence of the Hadley Circulation (HC), coupled to increased tropospheric drying in the expanded subtropical subsidence zone of the HC, under sustained warmer SST conditions.

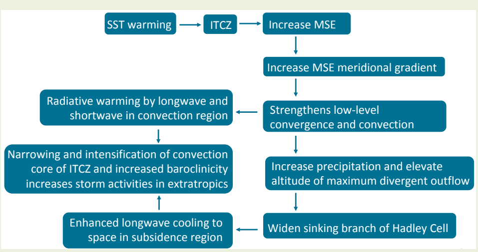

Figure 2. Flow chart indicating of the possible physical processes involved in CRCI in response to SST warming.

Experiment setup: Effects of cloud-radiation interaction are examined based on the differences between two 10-year (2007-2016) Goddard MMF simulations with (Control) and without (NoCRF) cloud-radiation feedback. [CRCI effect = Control – NoCRF]

Moist Static Energy Balance Equation

$$\frac{\partial \bar{s}}{\partial t} + \bar{v}\cdot\nabla\bar{s} + \bar{\omega}\frac{\partial \bar{s}}{\partial p} = Q_R + L(c-e) - \nabla\cdot\overline{s'v'} - \frac{\partial \overline{s'\omega'}}{\partial p}$$

$$\frac{\partial s}{\partial t} = DYN + Q_{MP} + Q_{SW} + Q_{LW} + Q_{Res} \sim 0, \quad \textit{for steady state}$$

s = moist static energy ($C_pT + gz$)

$DYN = -\left(\bar{v}\cdot\nabla\bar{s} + \bar{\omega}\frac{\partial \bar{s}}{\partial p}\right)$, dynamical tendency

Q_{MP}, heating by moist physics

Q_{SW}, shortwave heating

Q_{LW}, longwave heating

Q_{res} transients, unresolved subgrid processes

2. Results

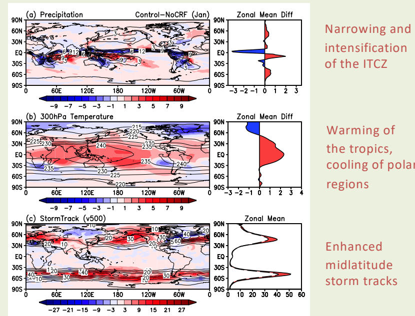

Figure 3. Difference between Control (full physics) and NoCRF (no cloud feedback) model experiments on a) precipitation, b) tropospheric temperature, and c) mid-latitude storm track activities, during January.

Zonal Mean Heat Balance in the Atmosphere

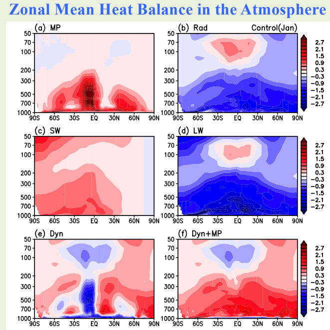

Figure 4. Zonal mean profiles showing contributions of various diabatic heating processes in the control climate: a) Q_{MP}, b) Q_{SW+LW}, c) Q_{SW}, d) Q_{LW}, e) DYN, and f) DYN + Q_{MP}

CRCI and Extreme Precipitation

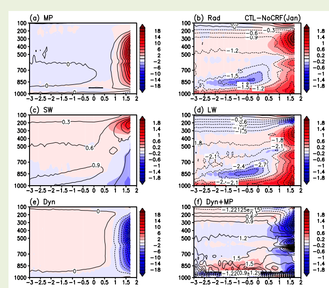

Figure 5. Impacts of CRCI on zonal mean heating terms as a function of rain intensity. January mean distributions of 10-year NoCRF experiment are shown as contours.

Modulation of AR activities and ITCZ convection by CRCI

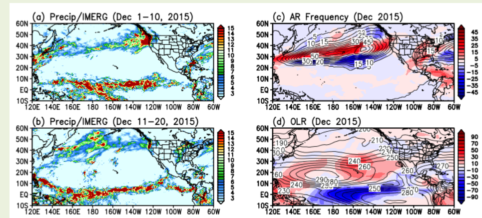

Figure 6. IMERG precipitation for (a) the first and (b) the second 10-day in December 2015. Right panels show (c) atmospheric river (AR) frequency and (d) OLR anomalies for December 2015. Contours indicate monthly values of December 2015.

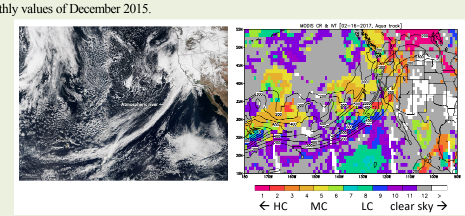

Figure 7. Example of an AR and cloud distribution shown with MODIS cloud regime (CR) (Courtesy of Lazaros Oreopoulos and his cloud group). Contour on right panel shows the vertically integrated water vapor transport from surface to 300hPa (IVT) based on 3-hourly MERRA2 data.

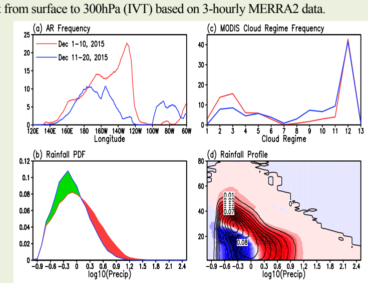

Figure 8. Comparison of AR Frequency (35N-55N) and associated changes in (b) rainfall PDF, (c) MODIS Cloud Regime (CR) frequency and (d) rainfall profile over the western USA (140W-120W, 30N-50N).

Modulation of vertical heating profile by CRCI
Future study

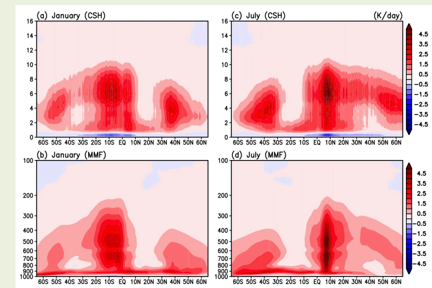

Figure 9. January mean latent heating profiles from (a) GPM (3HCSHv3) and (b) MMF model simulation. (c) and (d) are same as (a) and (b) except for July.

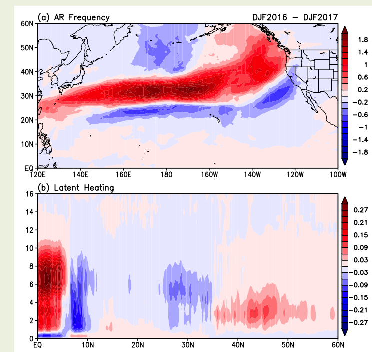

Figure 10. Difference of (a) AR frequency and (b) GPM latent heating profile between two winters (DJF 2016 and DJF2017).

3. Summary

Impacts of cloud-radiation-circulation interaction (CRCI) on organization of tropical convection, and extreme precipitation are examined by conducting two sets of 10-year simulations using the Goddard MMF (GMMF), with (Control) and without cloud radiation feedback (NoCRF) under prescribed SST from 2007-2016. Changes in clouds, precipitation and circulation, heating due to moist physics, shortwave and longwave radiation, and dynamical tendency have been examined based on the differences between Control and NoCRF experiments. Preliminary results show that:

- CRCI warms mid- to upper-tropospheric temperature, shifts deep convection to the warmer hemisphere (NH), increases equator-to-pole temperature gradient, and enhances mid-latitude storm tracks.
- Both SW and LW contribute to warming of the tropical troposphere, while LW cooling dominates in the subtropics and extratropics above clouds.
- Anomalous heating by deep convection and precipitation in the tropics is strongly balanced by dynamics (adiabatic cooling in ascending air) in the tropics, while anomalous LW cooling in the extratropics balances the heating due to increased poleward heat transport by the enhanced extratropical storm track.
- In the tropics and subtropics, the DTS effect is manifested in enhanced heating by both SW and LW, intensifying extreme precipitation in regions of heavy precipitation, and increased LW cooling in drier, less cloudy regions, accentuating the contrast between wet and dry regions, *i.e.*, wet-gets-warmer-and-wetter, dry-gets-cooler-and-drier.

Preliminary examination of active vs. non-active periods of Atmospheric River (ARs) events over the North Pacific, suggest possible roles of CRCI in modulating ITCZ convection, and frequency and intensity of ARs over the North Pacific, and extreme EPEs over US west coast during boreal winter.